Keawakapu Preliminary Injury Assessment

Prepared by

Matthew Parry[1], Robert O'Conner[2], Danielle Jayewardene[3], Nadiera C. Sukhraj[4], Jeff Phillips[4]

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[1]U.S. Department of Commerce, National Marine Fisheries Service, Restoration Center, Honolulu, Hawaii
[2]U.S. Department of Commerce, National Marine Fisheries Service, Habitat Conservation Division, Honolulu, Hawaii
[3]Joint Institute for Marine and Atmospheric Research, Research Corporation, University of Hawaii, Honolulu, Hawaii
[4]U.S. Department of Interior, Fish and Wildlife Service, Pacific Islands Field Office, Coastal Conservation Program, Honolulu, Hawaii

INTRODUCTION

The Keawakapu Artificial Reef project is located off the south coast of Maui (Figure 1), and was established by the State of Hawai'i Department of Land and Natural Resources (DLNR) in 1962. The artificial reef consists of different structures including 150 cars, 2,250 tire modules, 35 concrete slabs, and one vessel (the "St. Anthony") that have been deployed over time (DLNR, 2009) within a designated zone approximately 54 acres in size. The latest addition to the artificial reef, the first since 1990, was concrete Z-modules deployed in December 2009. These Z-shaped modules weigh about 2,800 lbs (~1.3 ton), and measure eight ft (2.4 m) long by four ft (1.2 m) wide with one foot (0.3 m) long legs projecting in opposite directions at each end. Fifty-two experimental hollow cubes measuring 4 ft (1.3 m) on a side and weighing 4,000 lbs (~1.8 ton) were deployed simultaneously.

On December 2, 2009, an American Marine barge deployed approximately 1,400 modules. The target depth was 60-120 ft (~20-40 m) of water within the official boundary points of the artificial reef zone, as listed in the approved Army Corps of Engineers permit (ACOE, 2005). However, during the deployment a number of modules were accidentally deployed on live coral reef habitat.

DLNR requested assistance from the National Marine Fisheries Service (NMFS) Restoration Center (RC) and Habitat Conservation Division (HCD) and the U.S. Fish and Wildlife Service (FWS) Coastal Conservation Program. DLNR asked NOAA and FWS to conduct a joint natural resource injury preliminary assessment independent from DLNR staff. In order to avoid any potential conflict of interest, DLNR staff were not involved in any phase of conducting this preliminary injury assessment. DLNR and FWS entered into an agreement on December 17 and agreed to a scope of work to be conducted.

NOAA and FWS conducted a preliminary of the natural resource injury using federal injury assessment guidelines found in the Oil Pollution Act of 1990 (OPA) as well as the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). The purpose of the pre-assessment was to define areas of injury from the December 2 incident. The preliminary assessment will help guide possible emergency restoration efforts, a more comprehensive natural resource damage assessment, and planning for appropriate restoration of lost habitat.

METHODOLOGY

The pre-assessment had three field objectives:

1) document the total number of deployed concrete modules causing reef injury
2) map the full spatial extent of injury
3) generally describe the injured habitats

Between January 5 and 7, 2010, NOAA and FWS biologists completed a total of fourteen survey dives on the Keawakapu injury site. The modules were mapped using two methods: 1) surface towed Garmin 76s GPS (Global Positioning System) units linked to digital photographs, and 2) an AquaMap™ underwater acoustic mapping system. Resource injuries were documented using digital photography and modules causing reef injury were counted.

Portable GPS units were attached to a surface buoy and towed by each of two dive teams (one team of NOAA staff and one team of FWS staff). Each GPS unit was set to log a continuous track of GPS coordinates every five seconds throughout the dives. Dive teams swam the perimeter of the area. Surface buoys (and GPS) were positioned directly overhead of underwater cameras when photos were taken to reduce errors associated with the angle of the line between the diver and the towed buoy. Using GPS Photo Link™ software the time stamps associated with each digital photo file were linked by time with the synchronized GPS track log coordinate producing geo-referenced photographs. These photographs were then plotted into ArcMap™ software and used to delineate specific areas and habitats.

Higher resolution coordinates of modules were taken using an AquaMap™ underwater acoustic transmitter/receiver system. Four baseline acoustic stations were deployed and a portable handheld transmitter/receiver was used to take relative positional data at the center of each module. A representative photograph was taken of each module for descriptive purposes. The more precise AquaMap™ coordinates were plotted on the larger spatial extent maps to verify coordinates obtained with the surface towed GPS units. The coordinates from this acoustic system resulted in geo-referenced data points with accuracy below 3 ft (~ 1 m). Due to time and technical constraints encountered when deploying the acoustic system at the depth ranges encountered (~ 75 ft/25 m) only one area of injury was mapped to this level of precision. However, all concrete modules causing reef injury were counted and photographed and all areas of injury were mapped with towed GPS-units.

All modules that landed partially or totally on reef were tagged with a unique identifying number laminated in plastic. The numbers were attached to the modules with a cable tie to one of the rebar handles. Four of the modules did not have accessible rebar and identifier tags were attached to adjacent dead coral. A photo was taken of each attached identifier tag. The identifier tags ensured that every module on the reef had been counted and prevented double counting.

RESULTS

Of the reported 1400 modules deployed, 125 were found to have landed partially or totally on coral reef habitat (Figure 2). All modules that landed on coral reef habitat were of the Z-module form; no hollow cube forms landed on reef. The remaining modules landed on sand or sand with beds of *Halimeda sp*. algae. The total area of the module deployment (including modules that landed on the reef) measured approximately 5 acres (~20,000 m^2). The majority of modules did not land on the reef, but dive teams surveyed a larger area to ensure all modules were accounted for. The total area surveyed for injury (estimated from the track logs and spatial maps) was approximately 12 acres (~ 50,000 m^2) (Figure 2). During the survey reef injuries from modules were discovered in two habitat areas, a main reef, and an adjacent patch reef. Surrounding these two habitat areas to the south, west, and north was sand and beds of *Halimeda sp*. algae (Figure 2). These areas are discussed in more detail below.

Modules were observed in a wide variety of orientations in all of the habitats. In general the configurations fell into four basic categories: (1) individual modules lying horizontally flat on the substrate (Fig. 3A), (2) several modules stacked together either partially or wholly overlapping each other (Fig. 3B), (3) modules lying partially or fully on edge (Fig. 3C), (4) fragmented and damaged modules (Fig. 3D).

Main Reef

The main reef in the survey area is part of a reef complex extending to the north and east (Figure 2). The section of main reef surveyed for injury was a ridge approximately 300 ft (~ 100m) wide (north/south) and at least 1500 ft (~ 500 m) long (east/west). The top of the main reef was in approximately 50 ft (~ 17 m) of water with the north side of the ridge sloping to > 100 ft (~ 33 m) and the south edge sloping to approximately 70 ft (~ 23 m). Twenty-five modules were concentrated in a central portion of the main reef on the southern edge of the area surveyed (Figure 2). The condition of the modules in this area varied. Some modules were undamaged and appeared to have impacted the bottom with relatively little physical force (Fig. 4A), but others were damaged, suggesting a greater impact force with the bottom (Fig. 4B, 4C). Most modules in this area of reef were solitary or in pairs, but a few small clusters of modules were observed (Fig. 2D). The density of modules found in this area was low.

An extension of the main reef was impacted by 45 modules with the majority of modules located along the southern edge (Figure 2). This oblong extension of reef was located on the eastern section of the surveyed area of main reef. This portion of reef was attached to the main reef at approximately 50 ft (~17 m) depth, extending southeast and sloping to the sand bottom at 70 ft (~23 m). The density of the modules on this extension was greater than that found on the main section of reef, and modules were frequently observed in overlapping clusters (Fig. 5A, 5B). Some modules were also clustered along the southern margin of the reef protrusion lying partly on sand, and several showed indications of substantial collision force with the substrate (Fig. 5C, 5D).

Patch Reef

Modules were also observed on a patch reef just south of the main reef (Figure 2). The patch reef was approximately 150 ft (~ 50 m) in diameter with the top at 50 ft (~ 17 m) depth and sloping to the sand bottom at 70 ft (~ 23 m). Fifty-five modules were clustered on the patch reef (Fig. 4A, 4B). Modules were observed across most of the patch reef. Many of the modules appeared to have experienced substantial collisions with the substrate and appeared to have slid down the reef slope causing additional damage to coral (Fig. 6C). Some modules lay partially in the sand at the reef/sand margin around the perimeter of the patch reef (Fig. 6D). Most of the hollow cube modules were found isolated and in clustered formation to the east and south of the patch reef.

Total Injury

The primary purpose of this preliminary assessment was to determine the type and extent of the injury. This pre-assessment was not intended to be a full scale natural resource damage assessment. Therefore, comprehensive quantitative data on species composition, ecological function, and coral colony size were not collected. The total injury was difficult to quantify using the information gathered from the preliminary assessment alone. Due to the variety of module configurations observed, some evidence of sliding, and the complexity of the habitat, a simple addition of the area of modules affecting the reef would not accurately quantify the total injury. Not all modules that landed on reef structure caused damage to coral colonies. A few modules were balanced on the colonies underneath, creating a heavily shaded environment. Corals that are currently alive and shaded by the modules will likely undergo a certain level of mortality in any of the emergency response alternatives. The dive teams could not determine if damage was caused by the drifting of modules or the positioning of the barge with the information that was provided.

GENERAL HABITAT AND SPECIES OBSERVATIONS

Coral

Coral cover was high (> 50%), and relatively homogenous across the main and patch reef sections. The coral community was predominantly composed of *Porites compressa*, encrusting and finger-like morphotypes of *Porites lobata*, and encrusting *Montipora capitata* (Fig. 7A, 7B). Colonies of *Montipora patula*, *Pocillipora meandrina*, *Pocillopora damicornis*, and *Pavona varians* were also observed. No larger coral colony mounds were noted and there appeared to be substantial coral fission which made identifying discrete colonies difficult. Broken pieces of *P. compressa* were observed in areas where modules had landed and then shifted and also where module fragments had rolled down slope (Fig. 1D, 5A, 5B, 6C). There was a limited abundance of reef cementing crustose coralline algae.

Macroinvertebrates

Within the area surveyed, divers observed over 100 crown-of-thorns starfish (*Acanthaster planci*). Patches of white skeleton where encrusting *P. lobata* tissue had been eaten were noted in some areas. The urchins *Tripnuestes gratilla*, *Echinothrix calamaris* and *Echinothrix diadema* were present on the modules, the reef substrate and sand, while *Heterocentrotus mammillatus* was only observed on the reef substrate. Herbivory by sea urchins on the cement modules was evident from feeding tracks in the turf algae. The sea cucumber *Holothuria atra* was found throughout the sand patches and the *Halimeda* sp. beds. The day octopus (*Octopus cyanea)* was observed on the patch reef resting on concrete. The state-protected black lipped pearl oyster (*Pinctada margaritifera*) was also present on areas of the reef.

Algae

Non-coral areas of the reef were covered mostly by filamentous turf algae. Macroalgal biomass was low, including a limited amount of crustose coralline algae, a primary cementing organism on coral reefs. *Halimeda* sp. beds were present across much of the sand bottom (Fig. 7C), but were not inspected during this pre-assessment.

Reef Fish

Fish species associated with reef and adjacent sand habitats observed during this pre-assessment are listed in Appendix A. Many of the fish species observed were closely associated with corals having finger and plate morphologies. Fish observations were not made in the *Halimeda* beds and data on these communities should be collected during subsequent field surveys. Large schools of ringtail surgeons (*Acanthurus blochii*), yellowfin goatfish (*Mulloidichthys vanicolensis*), and parrotfish juveniles were observed around the modules, both on the reef and in the sand.

EMERGENCY RESTORATION OPTIONS

Emergency restoration actions should be designed and implemented to prevent any further injury from occurring and remove potential conditions that could impede recovery. Three emergency restoration options are evaluated below based on their: (1) likelihood of causing further injury, (2) monetary cost, (3) effect on natural recovery of the injured resources (and lost ecological function), (4) likelihood of restoring human use, and (5) risk to human health and safety. The likelihood of further injury is considered because coral cover around the modules is high. Monetary cost is considered because the most cost effective option (given the same amount of restoration) should be preferred. The effect of any action on natural recovery is considered because actions that reduce the natural recovery time will reduce the total amount of injury and therefore the amount of compensatory restoration required. Human use is considered because the area is used for ocean recreation and fishing. The following three options represent a reasonable range of alternatives, but they should not exclude other options that could be developed. With any of the options, permitting issues would need to be addressed given that the currently deployed blocks are outside of the Department of the Army permitted area (Permit Number POH-2004-1134).

Option A: No action (leave the modules in place)

Given the depths of the modules (and their size) any further movement of the modules from wave action is unlikely. This no action option is unlikely to cause further direct injury and has the lowest initial cost. However overall costs may be greater over time as recovery of injured coral resources will be slow because coral will not recruit to and overgrow the modules as readily as it would the broken coral matrix beneath them. The State would consequently be responsible for restoration options that take into account the lost ecological resources over a longer recovery window. There may be a level of reduced recreational use of this area which would continue as long as natural recovery was slowed, as well as a loss of natural aesthetic value. There are no risks to human health associated with this option.

Option B: Full Removal

The full removal option entails removing all modules and associated fragments impacting reef regardless of their state and configuration. Modules could be moved by a team of divers using lift bags or barge mounted cranes and redeployed at an appropriate location. If pursuing this option the State should consult with relevant marine salvage companies or other entities that conduct such operations. This option may cause additional injury given that lateral motion of the modules during lifting and towing could create a larger injury footprint. Additional injury during the salvage operation could also result from dropping modules or having to set down a module on the reef during transport. The goal of any removal action would be to lift the modules vertically while minimizing any lateral motion, and then moving them without contacting the reef along the way. This action would most likely have the highest initial cost. Removing the modules would likely increase the rate of natural coral recovery and have a positive effect on recreational use in the area as well as aesthetic value. There would be some risks to human health and safety related to the operators because underwater salvage operations carry a level of inherent risk.

Option C: Partial Removal

This option entails removal of selected modules and associated fragments which could be extracted easily without further coral injury. Modules deemed too risky to move in terms of causing further damage would be left in place. The modules could be moved and redeployed at an appropriate location. This option should cause less injury than the full removal option, but would likely still result in additional injury. If pursuing this option the State should consult with relevant marine salvage companies or other entities that conduct such operations. Additional injury could also occur during the salvage operation. The cost associated with this option should be less than the full removal option. Partial removal of the modules would still result in an increased rate of natural coral recovery in those areas where the modules had been removed; however, those modules left in place would slow recovery of the impacted area. Removing some of the modules from the reef should have a positive effect (although less than full removal) on recreational use in the area and aesthetic value. There would be some risks to human health and safety related to the operators because underwater salvage operations carry a level of inherent risk.

RECOMMENDATIONS

Regardless of which emergency restoration actions are taken, the Federal agencies are available (if requested from DLNR) to assist with a thorough injury assessment that would more precisely quantify the injury related to the module deployment. This type of information would assist with designing future restoration projects so that the amount and type of restoration is equivalent to the amount and type of resources injured or lost. The additional information collected in a full assessment would also enable a more accurate projection of the recovery time of the injured resources. If complete or partial module removal is the selected emergency restoration action, the Federal entities could be available (if requested from DLNR) to provide on-site technical assistance during operations, quantify any additional injury associated with the activities, and re-estimate the time for natural recovery post-action.

For additional actions, NOAA and FWS recommend DLNR conduct restoration for the resource injury that occurred from the deployment of the modules including the interim loss until the projected reef recovery. Restoration plans should be developed in consultation with the resource agencies and the affected public.

Disclaimer

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References

DLNR. 2009. State to expand Maui's Keawakapu Artificial Reef on Monday. NR-313, November 25, 2009.

ACOE. 2009. POH-2004-1134. Permit for maintenance and expansion of existing artificial reefs under jurisdiction of the State of Hawaii. U.S. Army Engineer District, Honolulu.

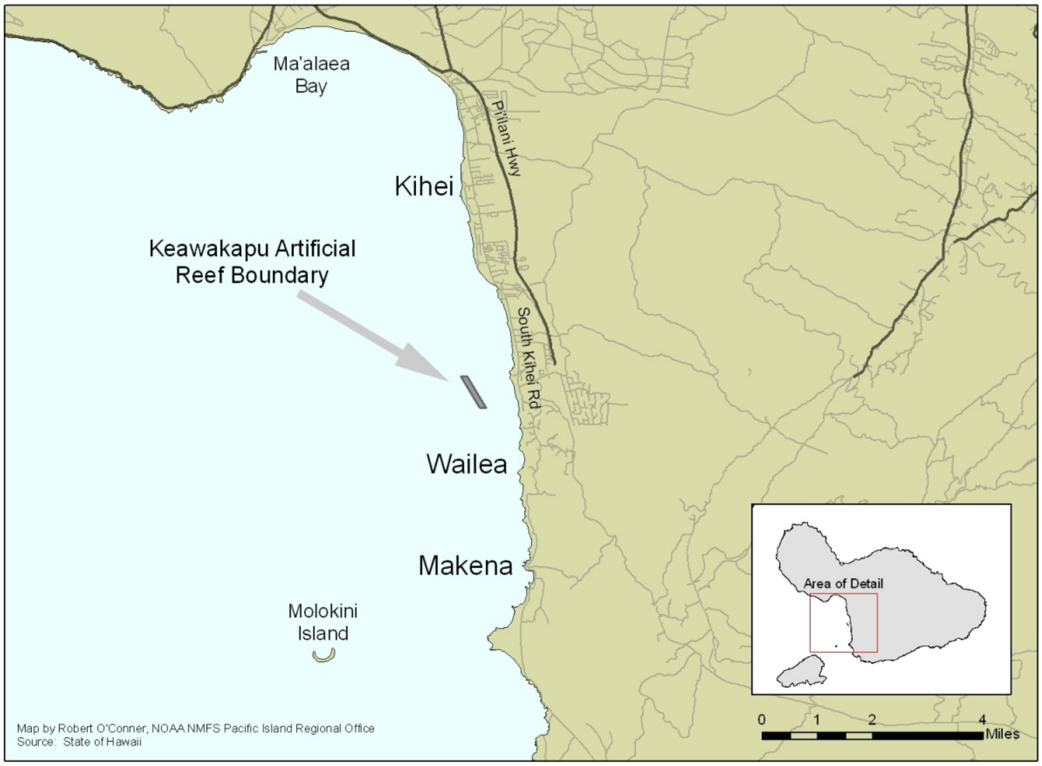

Figure 1. Overview of the Kihei coast on Maui showing the relative position of the Keawakapu Artificial Reef designated area. This polygon was generated using coordinates obtained from the DAR artificial reef website.

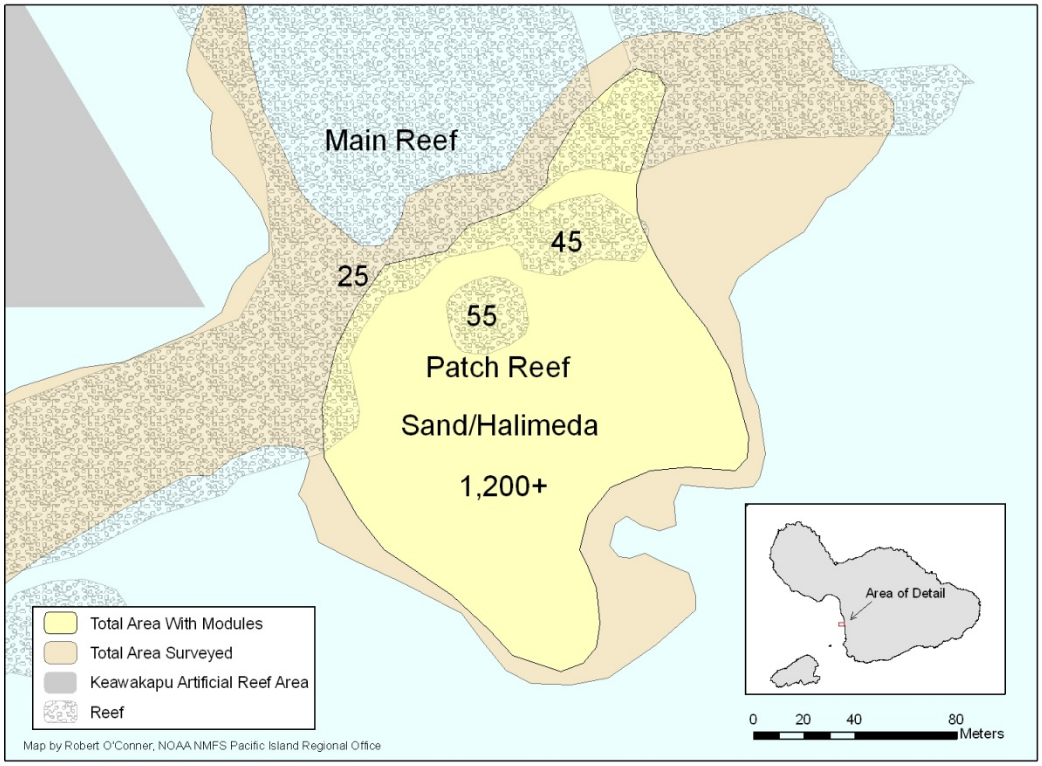

Figure 2. A detail map showing the area surveyed during the three-day pre-assessment project and the spatial extent of the module deployment. The numbers denote the number of modules found on the main reef (25), the extension from the main reef (45), and the patch reef (55). The remainder of the modules (1,200+) was found on sand or sand with *Halimeda sp.* habitat. The southeast corner of the designated Keawakapu Artificial Reef area can be seen on the top left of the map.

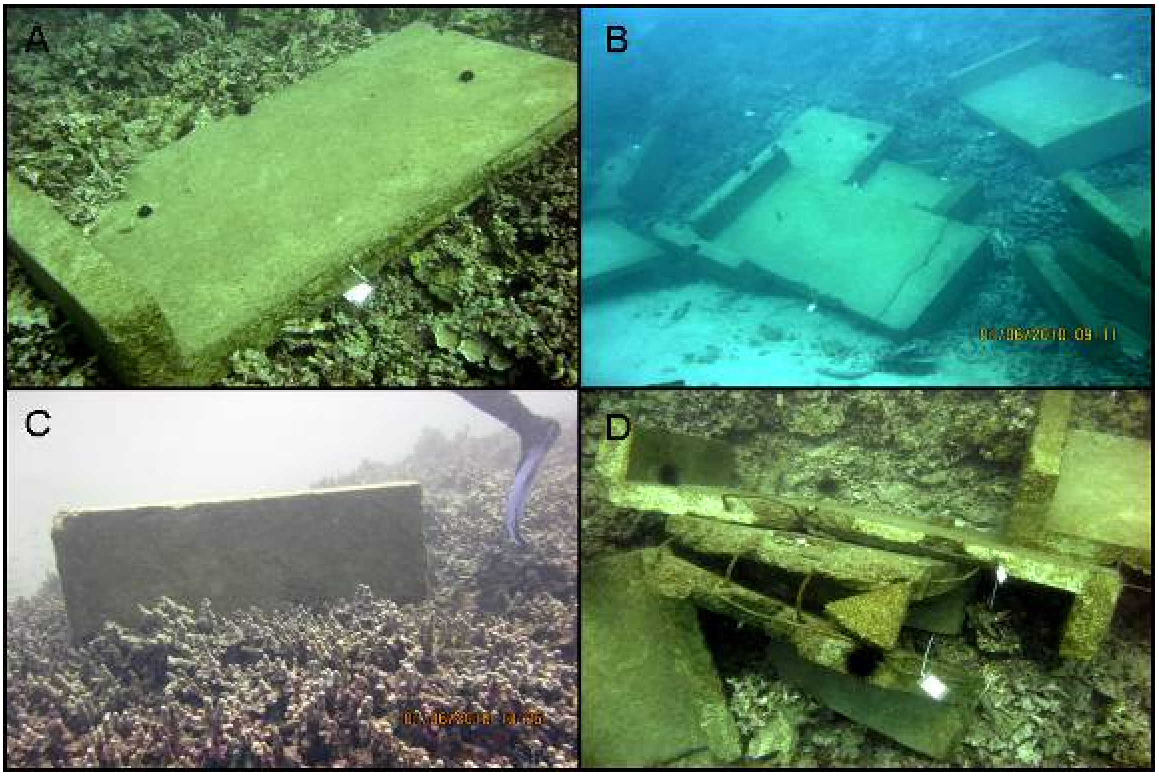

Figure 3. Four representative module orientations found on the reef.

A) An individual solitary module lying flat along one face.

B) A cluster of modules overlapping each other with some modules lying partially in sand.

C) An individual module lying upright along its long axis.

D) A cluster of modules showing signs of substantial collision with the reef (modules are fragmented and broken). A perimeter of broken coral can be seen surrounding the cluster indicating that the modules slid after impact.

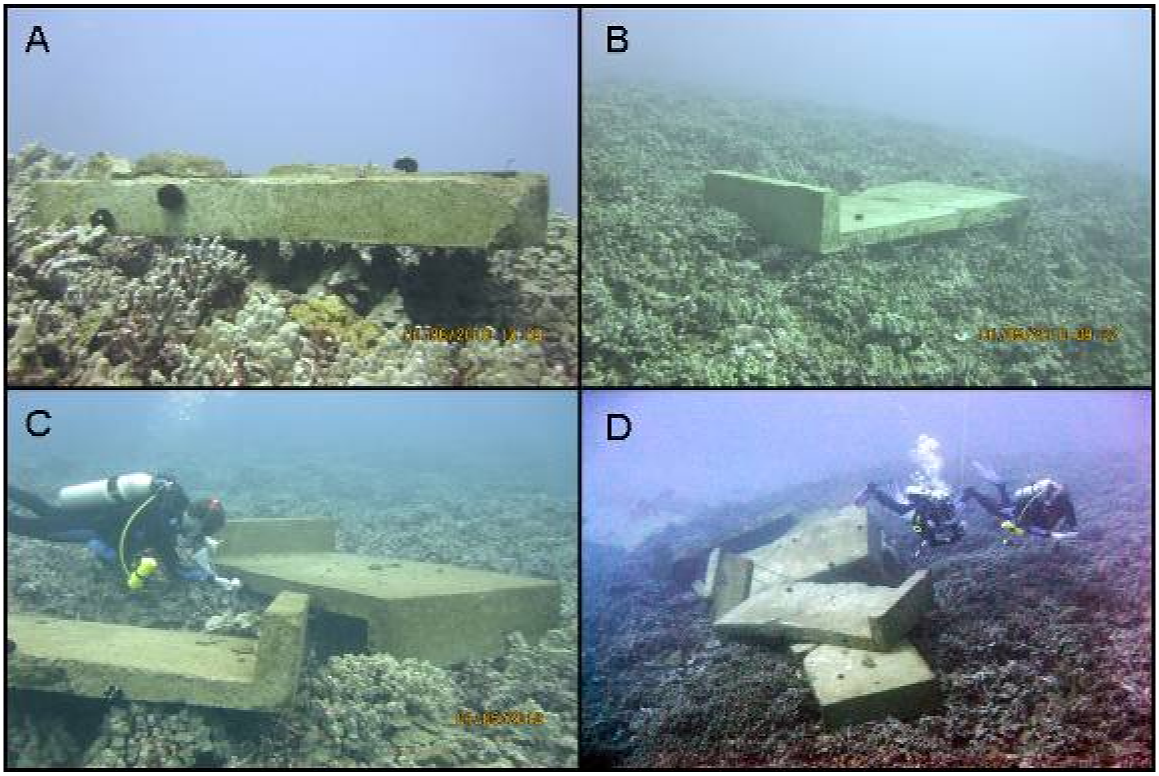

Figure 4. Modules found on the main reef area.

A) An individual module that appears to have settled on the reef without breaking all the coral underneath it. Intact coral can clearly be seen underneath the module, supporting its weight. Shading under the module is evident in the photo and will likely result in some coral mortality.

B) A solitary individual module showing a crack across the top indicating that it may have settled with substantial force.

C) A pair of modules on the main reef that was representative of the typical density of the modules in this area. Note intact coral can be seen under the module in the foreground.

D) A cluster of cracked and broken modules that was atypical of the density of modules in the main reef area.

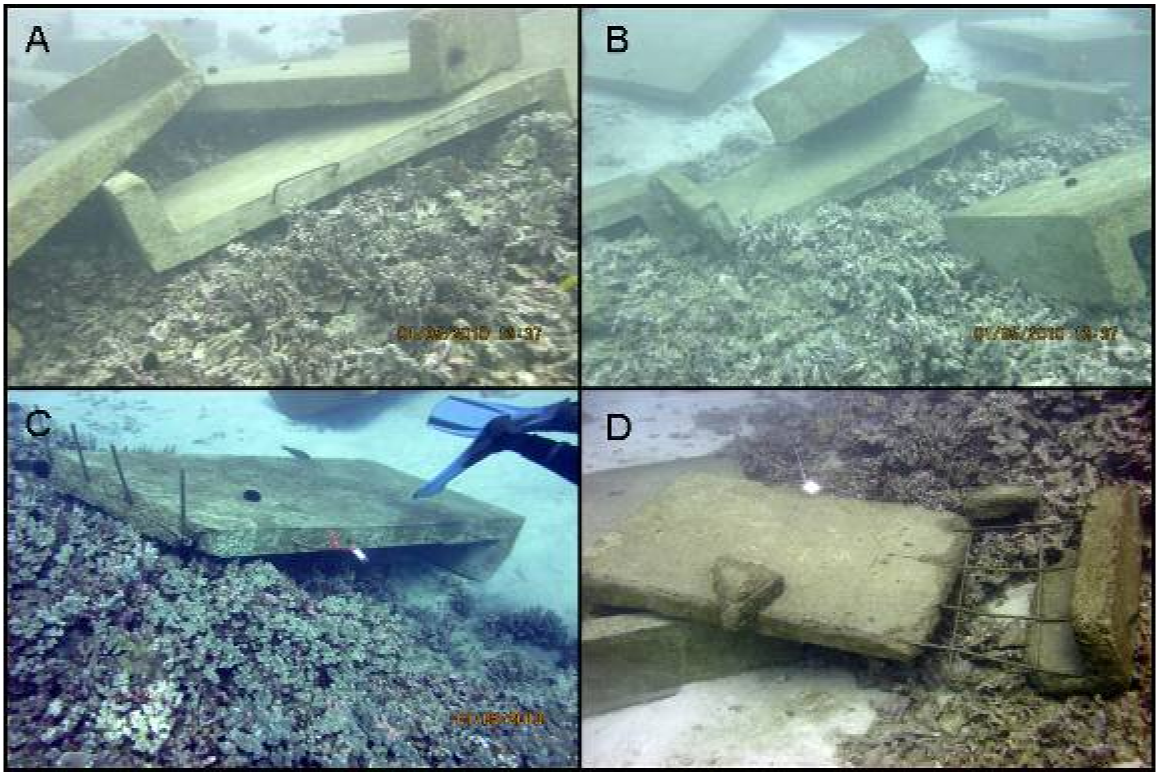

Figure 5. Modules found on the extension of the main reef.

A) An overlapping cluster of modules on the extension of the main reef. Broken coral can be seen in a perimeter around the modules indicating that they slid down slope causing additional injury to coral.

B) A typical overlapping cluster of modules on the reef perimeter showing evidence of sliding.

C) A module lying partially on reef and partially in sand. The edge of the module has been broken off exposing the internal rebar structure.

D) Overlapping modules lying partially in sand. The top module has been broken exposing the internal rebar framework. Module fragments can be seen nearby.

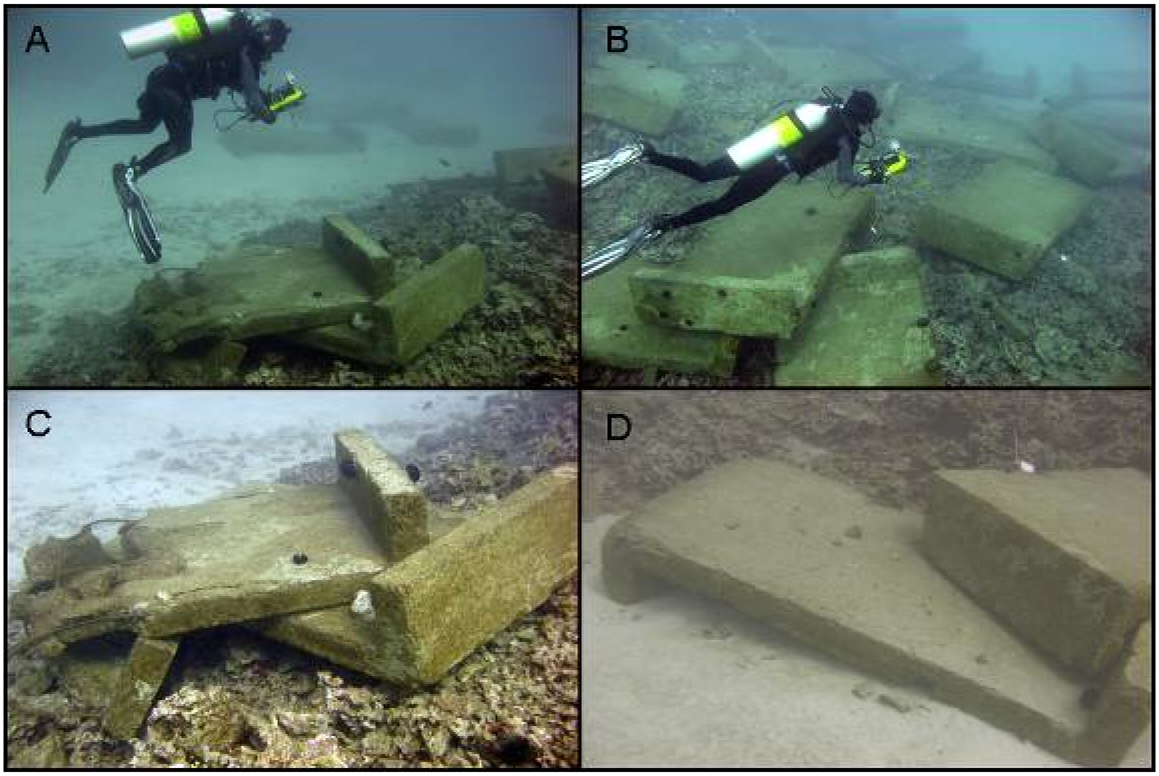

Figure 6. Modules found on the patch reef.

A) Overlapping modules on coral.

B) A representative photo showing the density of modules on the patch reef. Of all the reef areas surveyed, the density of modules was highest on the patch reef.

C) An overlapping cluster of modules showing signs of substantial collision with the reef. The modules are broken and a perimeter of injured coral can be seen surrounding the modules indicating that they slid down slope.

D) An overlapping cluster of modules along the reef/sand margin of the patch reef. The modules are lying partially in sand and partially on reef.

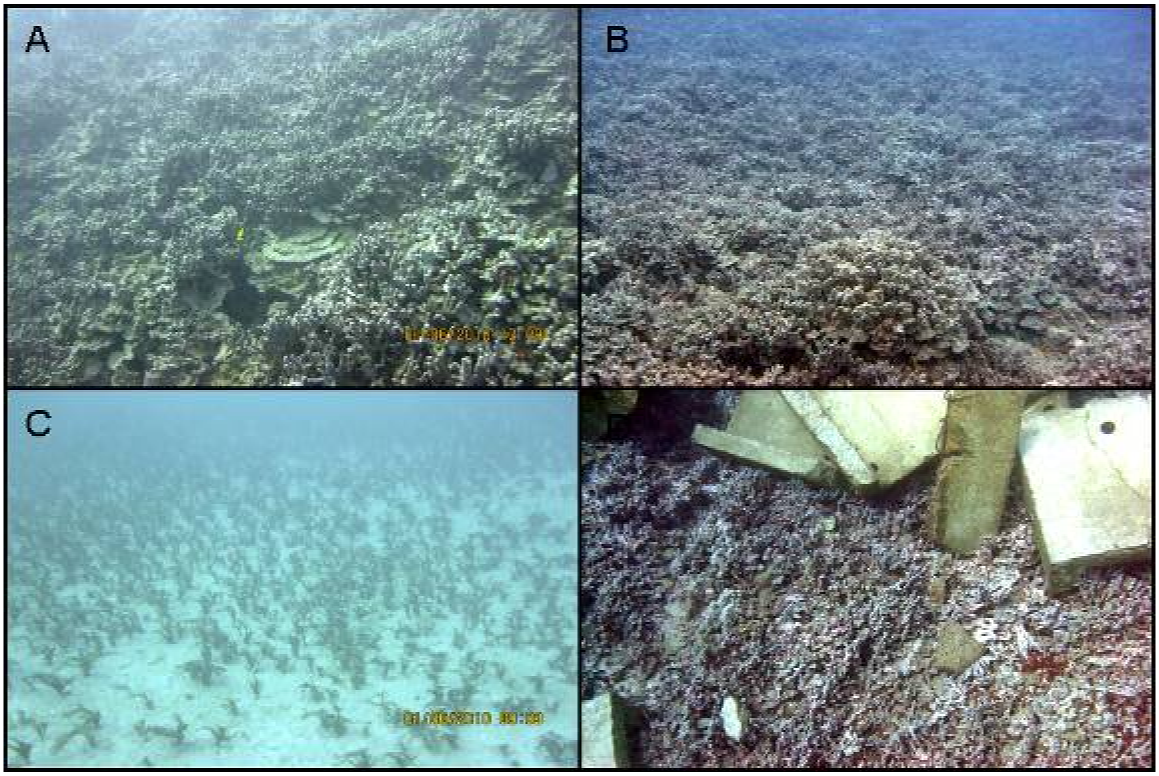

Figure 7. Representative photographs of the habitats and species in the area.

A) The reef showing several species and relative coral cover typical of all surveyed areas.

B) The reef showing several species and relative coral cover typical of all surveyed areas.

C) Sand bottom habitat with *Halimeda* sp. beds. This habitat surrounded the reef areas and contained the majority of deployed modules.

D) Fragments of broken *Porities compressa* coral seen commonly in most injured areas.

Appendix A

Keawakapu Artificial Reef: Reef fish species observed Wednesday, January 6, 2010 on reef habitat and adjacent sand

Family	Scientific Name	Common Name
Chaetodontidae	*Chaetodon unimaculatus*	teardrop butterflyfish
	Chaetodon multicinctus	multiband butterflyfish
	Chaetodon auriga	threadfin butterflyfish
	Chaetodon lunula	raccoon butterflyfish
	Forcipiger flavissimus	longnose butterflyfish
	Hemitaurichthys polylepis	pyramid butterflyfish
Acanthuridae	*Zebrasoma flavescens*	yellow tang
	Ctenochaetus strigosus	gold ring surgeonfish
	Zebrasoma veliferum	sailfin tang
	Acanthurus nigroris	blueline surgeonfish
	Acanthurus blochii	ringtail surgeon
	Naso lituratus	orangespine unicornfish
	Naso unicornis	bluespine unicornfish
	Naso hexacanthus	hornless unicornfish
Pomacentridae	*Dascyllus albisella*	Hawaiian domino
	Chromis hanui	chocolate dip chromis
	Chromis vanderbilti	blackspot chromis
	Chromis verater	threespot chromis
	Plectroglyphidodon johnstonianus	blue eye damsel
Scaridae	*Chlorurus sordidus*	bullethead parrotfish
	Scarus psittacus	palenose parrotfish
	Scarus perspicillatus	spectacled parrotfish
Labridae	*Bodianus bilunulatus*	Hawaiian hogfish
	Coris gaimard	yellowtail coris
	Coris flavovittata	yellowstrip coris
	Pseudocheilinus octotaenia	eightline wrasse
	Stethojulis belteata	belted wrasse
	Thalassoma duperrey	saddle wrasse
	Cheilinus unifasciatus	ringtail wrasse
Balistidae	*Melichthys vidua*	pinktail triggerfish
Monocanthidae	*Cantherhines dumerilii*	barred filefish
Serranidae	*Cephalopholis argus*	peacock grouper, roi
Cirrhitidae	*Paracirrhites arcatus*	arc eye hawkfish
	Paracirrhites forsteri	blackside hawkfish
Lutjanidae	*Lutjanus fulvus*	blacktail snapper
	Monotaxis grandoculis	bigeye emperor

Mullidae	*Mulloidichthys vanicolensis*	yellowfin goatfish
Family	**Scientific Name**	**Common Name**
Tetraodontidae	*Canthigaster coronata*	crowned toby
	Canthigaster epilampra	lantern toby
	Canthigaster jactator	Hawaiian spotted toby
Diodontidae	*Diodon hystrix*	porcupinefish
Holocentridae	*Myripristis kuntee*	pearly soldierfish
Aulostomidae	*Aulostomus chinensis*	trumpetfish
Fistularidae	*Fistularia commersonii*	cornetfish
Pomacanthidae	*Centropyge potteri*	Potter's angelfish
Sphyraenidae	*Sphyraena barracuda*	great barracuda
Priacanthidae	*Priacanthus meeki*	Hawaiian bigeye
Blennidae	*Cirripectes vanderbilti*	scarface blenny
Pinguipedidae	*Parapercis schauinslandi*	redspotted sandperch
Synodontidae	*Saurida flamma*	orangemouth lizardfish
Microdesmidae	*Ptereleotris heteroptera*	indigo dartfish
Muraenidae	*Gymnothorax undulatus*	undulated moray
	Gymnothorax meleagris	whitemouth moray
Myliobatidae	*Aetobatus narinari*	spotted eagle ray
Carcharhinidae	*Triaenodon obesus*	whitetip reef shark